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Light Curves and Period Changes of Type II Cepheids in the Globular Clusters M3 and M5

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ABSTRACT

Light curves in the B, V, and I_c passbands have been obtained for the type II Cepheids V154 in M3 and V42 and V84 in M5. Alternating cycle behavior, similar to that seen among RV Tauri variables, is confirmed for V84. Old and new observations, spanning more than a century, show that V154 has increased in period while V42 has decreased in period. V84, on the other hand, has shown large, erratic changes in period that do not appear to reflect the long term evolution of V84 through the HR diagram.

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1. Introduction

Type II Cepheids were among the first variable stars discovered within the globular clusters M3 (NGC 5272) and M5 (NGC 5904) (Pickering 1889; Packer 1890). Their initial discovery came long before the realization that Cepheids were pulsating stars (Shapley 1914), and even longer before Baade's (Baade 1956) discovery that Cepheids could be divided into two population groups. Until recently, the vast majority of observations available for globular cluster Cepheids were obtained photographically. This paper presents new B, V, and Cousins I_c band CCD light curves of the type II Cepheids V154 in M3 and V42 and V84 in M5, as well as some new photographic data. These variable stars were first observed more than a century ago, raising the possibility that their long term period changes may indicate the direction and speed of their evolution through the instability strip. Our new light curves, together with earlier observations and, in the case of V42, observations from the All Sky Automated Survey (ASAS) (Pojmanski 2002), are used to rediscuss the long term period changes of these variables.

2. Observations and Reductions

2.1. New CCD Data

Images of M3 and M5 covering 10 x 10 arcmin were taken with the 0.6-m reflector on the campus of Michigan State University during 2003-2005 using an Apogee Ap47p CCD camera. Additional Michigan State University observations were obtained of M5 in 2006 utilizing an Apogee Alta U47 CCD camera. Supplemental images were also obtained with two 0.4-m reflectors - in 2003 at the Brooks Astronomical Observatory of Central Michigan University with a Photometrics Star-1 camera and in 2004 with an SBIG ST-8 CCD on the Macalester College telescope.

As expected for observations from low altitude midwestern sites, seeing was usually not good, often being around 3 seconds of arc and sometimes worse. Images were obtained with Johnson B, V, and Cousins I_c filters. Exposure times ranged from one minute to six minutes depending on telescope and filter. Bias, dark, and flat field corrections were applied using standard techniques. The data were then reduced using Peter Stetson's DAOPHOT profile-fitting reduction package (Stetson 1987, 1994). The resulting instrumental b, v and i magnitudes were reduced to the standard system using equations of the form:

$$V = v + a_1(b-v) + c_1; \qquad (1)$$

$$B = b + a_2(b-v) + c_2; \tag{2}$$

$$I_c = i + a_3(v-i) + c_3. \tag{3}$$

Color terms were determined from observations of Landolt standard stars and stars within the open cluster M67 (Schild 1983, 1985; Landolt 1992). Occasionally, observations were not made through all three filters so that the usual means of obtaining color corrections could not be applied. In those cases, the color at the time of observation was determined from the typical color at the appropriate phase in the light curve. The color terms are sufficiently small and the light curves are sufficiently well established that this is not expected to be an important source of uncertainty.

Zero-point corrections to the standard system were determined from 5-6 uncrowded local standard stars within each cluster for which magnitudes had been determined by Stetson (2000). The type II Cepheids tend to be bluer than the other bright, uncrowded stars within the fields of our CCD images, and thus the local Stetson standards are redder (by 0.5 to 0.8 in $B-V$) than the target variables in both M3 and M5. The redder colors of the local standards will introduce error in the standard magnitudes for the Cepheids if there is a significant error in the coefficients of the color transformation equations. We have avoided extremely red local standards, and the transformation coefficients were determined separately for the Michigan State University, Central Michigan University, and Macalester College observations, which should minimize uncertainties from this source. Nonetheless, systematic errors of about 0.01 magnitude are possible.

The photometry of the three Cepheids is listed in Table 1. The filter, variable star identification, heliocentric Julian date, observed magnitude, uncertainty, and the source of the individual observations are listed in columns 1 through 6, respectively. In column 6, MSU is used for observations obtained at the Michigan State University observatory, CMU for observations obtained at the Central Michigan University observatory, and MAC for observations obtained at the observatory of Macalester College. The uncertainties listed in Table 1 reflect the formal uncertainties in the photometry as propagated through the daophot program and the application of the transformation equations. Heliocentric Julian Dates were determined from UTC of mid-exposure without application of the, in these cases, insignificant ΔT correction for the difference between UTC and uniform ephemeris time (Sterken 2005).

2.2. New Photographic Data

Because relatively few observations of V42 and V84 in M5 had been published between 1976 and 2003, one of us (W.O.) searched the plate vault of the Yerkes Observatory for plates of this cluster taken during this time period. Fourteen useful plates, all taken in 1982-83, were located. These are IIa-O plates taken with a BG1 filter, so that magnitudes estimated from these plates approximate those in the B photometric bandpass. W.O. made eye estimates of V42 and V84 on the plates, interpolating among standard stars A, B, E, and F in Coutts Clement & Sawyer Hogg (1977), adopting the B magnitudes for these stars given in Arp (1962). The estimated uncertainty of each estimate is about 0.15 magnitude. The resultant photometry is listed in Table 2.

2.3. ASAS Data

V42 is sufficiently far from the center of M5 that V-band photometry for it has been obtained in ASAS (Pojmanski 2002). We have extracted 353 *V*-band observations labeled of quality A (the best quality) from the photometry list for the ASAS object designated 151825+0202.9. Because the pixels of ASAS are relatively big (15 arc seconds), we have used only data from the smallest ASAS aperture (2 pixels in diameter). The listed uncertainties on the magnitudes are typically 0.03 to 0.05 magnitudes.

3. Periods and Light Curves

The best periods for the variables were determined using the Phase Dispersion Minimization routine (Stellingwerf 1978) as implemented in IRAF [1], the period04 program (Lenz 2004), and a discrete Fourier transform as implemented in the Peranso software suite [2]. These methods all yielded consistent results and provided periods which were then used to construct phased light curves. The results for each star are presented below. The adopted uncertainties in the derived periods are a combination of the uncertainties given by the period04 routine and from visual inspection of the light curves.

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[1] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

[2] http://www.peranso.com/

3.1. V154 in M3

The type II Cepheid V154 in M3, discovered in 1889, was the first periodic variable star to be identified within a globular cluster (Bidelman 1990). However, because of its proximity to the center of the cluster, it has been omitted in many photometric studies of the variable stars in M3. The best period for our 2003-2004 data was found to be 15.29 ± 0.02 days, close to the period of 15.2842 days used by Arp (1955) and adopted in the O-C diagram of Hopp (1980). The B, V, and I_c phased light curves of V154 in M3 are shown in Figure 1.

The scatter about the mean light curves in Figure 1 is larger than the formal photometric uncertainties (typically 0.02 or 0.03 mag). V154 is close enough to the center of the cluster that there can be some blending with neighboring stars, especially on our nights of poorer seeing, and that is very likely responsible for some of the scatter in the light curves despite our use of a profile-fitting photometry technique. Bakos et al. (2000) note that in their observations the image of V154 is blended with that of an RR Lyrae star, V268, which would also be the case with our observations. Nonetheless, it is possible that some of the scatter reflects real changes in the variability of V154. In a study of the light curve of the field type II Cepheid W Virginis (main period = 17.27 days), Templeton & Henden (2007) noted that the light curve of that star showed a scatter of about 0.1 magnitude, much larger than the 0.01 mag expected from observational error alone. They concluded that the light curve of W Vir could not be completely described by a single periodicity, and were able to identify two additional periodicities that contributed to the observed light curve. Our data for V154 are less extensive than the W Vir data obtained by Templeton & Henden (2007), and are not adequate to reveal any secondary periodicity for V154 comparable to those found in W Vir. However, the possibility that some of the scatter in our light curves of V154 may reflect real cycle to cycle differences should be kept in mind.

3.2. V42 in M5

In contrast to V154, V42 in M5 is relatively uncrowded. The derived period for V42 from our 2003-2006 observations is 25.735 ± 0.015 days, and this has been used to produce the light curves shown in Figure 2. The scatter in the light curve of V42, though smaller than that of V154, is still slightly larger than expected from the formal observational errors. Though some of this may reflect sources of observational uncertainty not included in the formal error analysis, we cannot exclude real fluctuations in the light curve as a source of scatter. For comparison, the period given by Coutts Clement & Sawyer Hogg (1977) is 25.738 days. The maxima, minima, and mean magnitudes derived from our B and V light curves are in good agreement with those from the more sparsely covered B and V light curves observed photoelectrically by Arp (1957).

The light curves of V42 from the Yerkes and ASAS data are shown in Figures 3 and 4, respectively. The Yerkes data are plotted using the same 25.735 d period adopted for the CCD light curves. While the points are sparse and have large uncertainties, the maximum and minimum are consistent with the CCD photometry for B. The period that best fits the ASAS observations from JD 2451930 until 2455057 (2001-2009) is 25.720 ± 0.003 days, and this has been used to construct the ASAS light curve. The V amplitude from the ASAS data is smaller than seen in our observations or in those of Arp (1957), and the mean magnitude is brighter. This probably occurs because, even with the smallest aperture, the ASAS pixels are too big to eliminate the contribution of neighboring stars to the aperture photometry. Nonetheless, the large number of data points and the long interval of time coverage make the ASAS observations of V42 very useful for the discussion of its period changes.

3.3. V84 in M5

V84 is in a more crowded field than V42, and its photometry undoubtedly suffers from that circumstance. The period determination for V84 also turned out to be more complicated than for V42. We first consider only our observations from 2003 through 2005. The V84 photometry for these years can be approximately fit with a period of 26.93 ± 0.02 days. Figures 5 and 6 show the light curves for this period for the CCD and Yerkes data, respectively. This period, however, leaves larger than expected scatter in the CCD light curves. It is also significantly longer than the period of 26.42 days used by Coutts Clement & Sawyer Hogg (1977).

Arp (1955) suggested that, while a period of 26.5 days described the main pulsation of V84, the light curve of V84 might be better described with a period twice as long. We carried out a period search in the vicinity of twice 26.9 days and obtained a best fit with a period of 53.95 ± 0.03 days. Figure 7 shows the 2003-2005 light curve of V84 plotted with this period, which is approximately but not exactly twice 26.93 (53.86 d). The scatter in the observed curves is reduced, although there are some gaps in phase coverage. The light curves show some evidence of alternating deep and shallow minima. RV Tauri stars are known to sometimes show alternating deep and shallow minima, e.g., Gillet (1992), and the light curve of V84 might therefore be indicative of low-level RV Tauri type behavior.

More complications arise when the observations from 2006 are included. The 2006 observations cannot be well-phased with the earlier data with either the 26.93 day or the 53.95 day periods, in both cases showing a significant phase shift between the two data sets (see Figure 8). In fact, no single period can provide a light curve for V84 that does not show large scatter when observations from 2003 through 2006 are combined. As we discuss below, abrupt changes in the period, and hence phase shifts, of V84 have been noted before, and the 2006 observations likely indicate

another such jump.

While the period solutions for V42 in M5 have shown little change over time, that is not the case for V84. This will be discussed in detail in §4.2, but we note that our period of 26.93 days is significantly longer than the 26.42 days used by Coutts Clement & Sawyer Hogg (1977) in plotting their light curve. In any particular observing season, lasting 3 or 4 months, the difference between a light curve with a 26.42 day period and a 26.93 day period is not large (less than about 0.05 in phase). However, over the span of two observing seasons, i.e. about a year, the difference can amount to a fifth of a cycle. The smaller number of observations in 2006 makes it impossible to determine the exact period during that year, and we cannot distinguish between a period of 26.4 and 26.9 days from the 2006 data alone.

4. Period Changes

4.1. M3

The long term period behavior of V154 in M3 was studied by Hopp (1980), using observations made between Julian dates 2416604 and 2442862, a span of 72 years from 1904 to 1976. We have expanded the interval of the period study to just over a century. In Table 3, we list the heliocentric Julian date (HJD) representing the epoch of maximum as determined from a given set of observations, the phase of maximum light calculated from the ephemeris of Arp (1955) ($JD_{max} = 2424627.55d + 15.2854E$, where JD_{max} is the date of maximum light and E the cycle number), the estimated uncertainty of the phase of maximum, and the source of the data. We have combined the three closely spaced maxima reported in Arp (1955) into a single representative point. We have chosen to be conservative in assessing the accuracy of the times of maximum, and thus in some instances assign larger uncertainties than were used by Hopp (1980). Unpublished observations of V154 from the study of M3 variables by Strader et al. (2002) were used to add an additional epoch of maximum.

Figure 9 shows a possible increase in period for V154 early in the observational record and, with more certainty, an increase in period after JD 2,450,000. A period of 15.2854 days adequately represents the observations made between JD 2,420,000 and JD 2,450,000. The sudden increase in phase for the more recent observations indicates an increase in period, but the gap in the observations before JD 2451256 makes it difficult to tell exactly when that period increase happened. If we assume an abrupt increase in period near JD 2,450,000, then we find that the period increased to about 15.296 days. That period is larger than the value of 15.29 ± 0.02 days found from the 2003-2005 observations alone, but it is within the estimated one sigma error bar of our period.

4.2. M5

Coutts Clement & Sawyer Hogg (1977) studied the long term period behavior of V42 and V84 using mainly photographic data spanning the 87-year interval from 1889 to 1976. To their compilation of data we can add the results from our observations, plus several additional results from observations made by others since 1976, which extend the studied time interval to about 120 years for V42 and 109 years for V84.

In discussing the period changes of V42, we have adopted the fiducial period (25.738 days) and epoch of zero-phase (HJD 2441102.7) used in Coutts Clement & Sawyer Hogg (1977). Additional epochs of maximum for V42 not included in Coutts Clement & Sawyer Hogg (1977) are listed in Table 4 which includes an epoch of maximum determined from unpublished photometry of V42 provided by T. M. Corwin (private comm.). Coutts Clement & Sawyer Hogg (1977) concluded that the period of V42 had been relatively stable with a period near 25.738 days since 1889, but that there had been a small period decrease of about 0.007 day. They noted that the change could have been occurring continuously, or that there could have been an abrupt period decrease in the 1940s. In the phase diagram for V42 shown in Figure 10, a more dramatic decrease in period is apparent. Until JD 2,435,000, the phase diagram is well described by a period of 25.738 ± 0.004 days. As found by Coutts Clement & Sawyer Hogg (1977), there is evidence for a slight decrease in period after that date. Between JD 2,435,000 and JD 2,441,000 the phase diagram can be well fit with a period of 25.731 ± 0.004 days. Between JD 2,441,000 and JD 2,455,000, the phase diagram is well fit with a period of 25.720 ± 0.003 days. As in the study of Coutts Clement & Sawyer Hogg (1977), the phase diagram does not let us determine whether the period changes are actually abrupt. However, the phase diagram in Figure 10 is slightly better fit by three straight line segments than by the parabola that would indicate a constant rate of period change. Burwell et al. (1995) in their abstract reported a period of 25.725 days based upon their unpublished photometry of V42, consistent with the decline in period found here.

In addressing the period change behavior of V84, we adopted a fiducial period of 26.42 days and epoch of zero-phase of HJD 2441129.6, again consistent with those used in Coutts Clement & Sawyer Hogg (1977). Additional epochs and phase shifts, beyond those given in Table V of Coutts Clement & Sawyer Hogg (1977) are listed in Table 5. Following Coutts Clement & Sawyer Hogg (1977), we use only the shorter period for V84 and not the 53 day double period in discussing the period change behavior. The observations in the literature are often not adequate for addressing phase shifts using the longer period, but its neglect may introduce some extra scatter into the phase shift diagram. The shifts in phase versus Julian Date are shown in Figure 12. In that figure we are faced with a much more confusing situation than was evident in Figures 9 or 10, a circumstance to which Coutts Clement & Sawyer Hogg (1977) have already called attention. The scatter in the phase shifts implies changes in period (or jumps in phase), and the changes are sufficiently large that it

is not always clear whether the count of cycles between observed epochs is correct.

Barnard (1898) determined the period of V84 to be 26.2 days based upon visual observations obtained with the Yerkes 1-m telescope. Arp (1955) obtained photographic observations of the M5 Cepheids and later reported additional photoelectric observations for the pair (Arp 1957), confirming his earlier report of the existence of alternating cycle behavior for V84. The periods given in Arp (1957) are 26.62 ± 0.03 days for the shorter cycle, and 53.24 ± 0.2 days for the doubled cycle. Wallerstein (1958) used his observations and those of Arp (1955) to determine a period of 26.54 days but also found evidence for alternating minima. By far the most extensive previous study of the period of V84 is the study of Coutts Clement & Sawyer Hogg (1977). They determined that during the 1930s and 1940s, the period of V84 remained nearly constant at 26.42 days. They found that during the 1950s, the period increased by about 0.2 days before decreasing again. There may have been another period jump in 1970, but by 1971 the period had settled again at 26.42 days. Our light curves of V84, and Figure 11, indicate an even more extreme increase in period to 26.93 days between 2003 and 2005. The phase shift shown in Figure 8 between the 2003-2005 and 2006 light curves for V84 suggests that its period has declined again, perhaps to near 26.8 days. Further observations are needed to confirm the exact value of the period for 2006 and later years.

5. Location in the Color-Magnitude Diagram

Long period type II Cepheids such as V154 and V42 (and also V84, if one includes variables with stronger RV Tauri-like behavior) tend to be brighter than expected from an extrapolation of the period-luminosity relation as determined from shorter period type II Cepheids (see, for example, Figure 5 in Bono et al. (1997)). In order to place V154, V42, and V84 onto a color-magnitude diagram, we derive their intensity-weighted mean V magnitude and magnitude-weighted colors, $(B-V)$ and $(V-I)$. These values and their uncertainties are listed in Table 6. Absolute V magnitudes, as derived below, are also listed. The estimated uncertainty for $< V >_{int}$ is about 0.02 for V42 and 0.03 for V84 and V154. The estimated uncertainties for the mean colors are about 0.03 for V42 and 0.04 for V84 and V154.

Arp (1957) derived a mean V magnitude of 11.22 for V42 with a mean $B-V$ color of 0.60, in good agreement with our results. Arp (1957) did not obtain a large enough number of observations to derive mean magnitudes and colors for V84. Carney et al. (1998) refer to unpublished BV photometry of V42 which gave $< V > = 11.15$, which is slightly brighter than our value. We have not found in the literature any complete light curves of V154 on the BVI_c system, but partial light curves are given in Benkő et al. (2006). It is not possible to calculate mean magnitudes from the Benkő et al. (2006) observations, and their observations show significant scatter at a given phase (as do ours), but their magnitudes may be slightly brighter than ours.

To determine absolute V magnitudes (M_V) for the Cepheids, we referenced their brightnesses to the RR Lyrae variables in M3 and M5. The mean $< V >_{int}$ magnitudes for RR Lyrae stars in M3 and M5 are about 15.64 and 15.07, respectively (Cacciari et al. 2005; Reid 1996; Storm et al. 1991). We convert these to absolute magnitudes using an absolute magnitude of 0.59 for RR Lyrae stars of [Fe/H] = -1.5 and $\Delta M_V / \Delta [Fe/H] = 0.214$ (Cacciari & Clementini 2003). Assuming [Fe/H] = -1.5 for M3 and -1.2 for M5, (Zinn & West 1984; Cacciari et al. 2005; Yong et al. 2008), we obtain the absolute magnitudes shown in Table 6. The resultant locations of the variables in the color-magnitude diagrams are shown in Figure 13, adopting $E(B-V) = 0.01$ for M3 and 0.03 for M5 (Cacciari et al. 2005; Reid 1996; Storm et al. 1991). Also plotted in Figure 12 are type II Cepheids in globular clusters from the tabulation in Nemec et al. (1994). Following Table 4 in Nemec et al. (1994), a few variables with slightly discordant measures by different observers are plotted more than once. All three of our variables, but especially V42 and V84, fall near the upper bound of the type II Cepheid instability strip, and near the transition to RV Tauri behavior (see also Wallerstein & Cox (1984) and Bono et al. (1997)).

6. Discussion of the Period Changes

Theory predicts that long period type II Cepheids enter the instability strip either while undergoing blueward instability loops from the asymptotic red giant branch as a consequence of helium shell flashes, or during final blueward evolution as the hydrogen burning shell nears the surface of the star (Schwarzschild & Harm 1970; Mengel 1973; Gingold 1985; Clement et al. 1988; Bono et al. 1997). Bono et al. (1997) found that, for the lower mass but brighter Cepheids, the instability strip could be crossed two or three times as a consequence of thermal pulses.

The period of a pulsating star is linked to its density via Ritter's pulsation equation, $Q = P\sqrt{\rho}$, where Q is the pulsation constant, P is the period, and ρ is the mean stellar density. The pulsation period of a Cepheid is often its most accurately known property, and, as noted long ago by Eddington (1918), a small change in the structure of the Cepheid will reveal itself as a change in pulsation period before it can be recognized in any other measured quantity. Each of our three stars showed long term period change behavior, but the changes are different in each case. V154 showed a modest increase in period consistent with movement to the red in the instability strip. V42 showed a decrease in period, consistent with movement to the blue. If these period changes indicate the long term evolution of these stars, V154 could be interpreted as being on the redward evolving, and V42 on the blueward evolving portion of the instability loops predicted by theory during shell helium burning. Alternatively, blueward moving V42 might be in the final blueward evolutionary phase. In neither case, however, is a parabolic fit to the phase diagram, implying a constant rate of period change, significantly better than the assumption of abrupt period changes.

Using the theoretical timescales of Gingold (1976), Clement et al. (1988) found that one might expect a rate of period decrease of $P^{-1}dP/dt = -0.0005$ to -0.002 cycles per 100 years during the final quiescent blueward evolving stage. The observed decrease in the period of V42 is about $\Delta P/P = -0.0007$ over 120 years, consistent with that expectation.

Although V42 and V84 are both near the luminosity dividing type II Cepheid and RV Tauri behavior in the HR diagram (Wallerstein & Cox 1984; Bono et al. 1997), V84 showed period changes much more erratic than those of V42. V84 is not, however, the only type II Cepheid exhibiting period fluctuations. Clement et al. (1988) found that period fluctuations were not unusual in type II Cepheids in globular clusters, although rarely do they seem to reach the extent exhibited by V84. Apparently random period fluctuations have also been observed in the O-C diagrams of other variable stars (Berdnikov et al. 2009; Turner et al. 2009). V1, a 15.5 day period Cepheid in the globular cluster M12, does perhaps show jumps in the phase shift diagram on a scale similar to that of V84 (Clement et al. 1988). V84 shows evidence of RV Tauri behavior, and strong cycle-to-cycle period fluctuations have been observed for RV Tauri stars in the field, e.g. Percy & Coffey (2005). However, Clement et al. (1988) do not report RV Tauri type behavior for V1 in M12, so that these irregular periods appear not to be limited only to long period variables near the RV Tauri domain in the HR diagram.

7. Acknowledgements

REFERENCES

Arp, H. C. 1955, AJ, 60, 1

Arp, H. C. 1957, AJ, 62, 129

Arp, H. 1962, ApJ, 135, 311

Baade, W. 1956, PASP, 68, 5

Bakos, G. A., Benko, J. M., & Jurcsik, J. 2000, Acta Astronomica, 50, 221

Barnard, E. E. 1898, Astronomische Nachrichten, 147, 243

Barnard, E. E. 1906, Astronomische Nachrichten, 172, 345

Benkő, J. M., Bakos, G. Á., & Nuspl, J. 2006, MNRAS, 372, 1657

Berdnikov, L. N.,Henden, A. A., Turner, D. G., & Pastukhova, E. N. 2009, Astronomy Letters, 35, 406

Bidelman, W. P. 1990, Information Bulletin on Variable Stars, 3543, 1

Bono, G., Caputo, F., & Santolamazza, P. 1997, A&A, 317, 171

Burwell, T. C., Corwin, T. M., Carney, B. W., Latham, D. W., & Danford, S. C. 1995, Bulletin of the American Astronomical Society, 27, 1429

Cacciari, C., & Clementini, G. 2003, Stellar Candles for the Extragalactic Distance Scale, 635, 105

Cacciari, C., Corwin, T. M., & Carney, B. W. 2005, AJ, 129, 267

Carney, B. W., Fry, A. M., & Gonzalez, G. 1998, AJ, 116, 2984

Clement, C. M., Hogg, H. S., & Yee, A. 1988, AJ, 96, 1642

Coutts Clement, C. M., & Sawyer Hogg, H. 1977, JRASC, 71, 281

Eddington, A. S. 1918, MNRAS, 79, 2

Gillet, D. 1992, A&A, 259, 215

Gingold, R. A. 1976, ApJ, 204, 116

Gingold, R. A. 1985, Memorie della Societa Astronomica Italiana, 56, 169

Greenstein, J. L. 1935, Harvard College Observatory Bulletin, 901, 11

Hopp, U. 1980, Information Bulletin on Variable Stars, 1857, 1

Kholopov, P. N. 1972, Astronomicheskij Tsirkulyar, 676, 7

Landolt, A. U. 1992, AJ, 104, 340

Lenz, P. 2004, Communications in Asteroseismology, 144, 41

Meinunger, I. 1980, Zentralinstitut fuer Astrophysik Sternwarte Sonneberg Mitteilungen ueber Veraenderliche Sterne, 8, 161

Mengel, J. G. 1973, IAU Colloq. 21: Variable Stars in Globular Clusters and in Related Systems, 36, 214

Nemec, J. M., Nemec, A. F. L., & Lutz, T. E. 1994, AJ, 108, 222

Packer, D.E., 1890, English Mechanic, 51, 378

Percy, J. R., & Coffey, J. 2005, Journal of the American Association of Variable Star Observers (JAAVSO), 33, 193

Pickering, E. C. 1889, Astronomische Nachrichten, 123, 207

Pojmanski, G. 2002, Acta Astronomica, 52,397

Reid, N. 1996, MNRAS, 282, 304

Schild, R. E. 1983, PASP, 95, 1021

Schild, R. 1985, PASP, 97, 824

Schwarzschild, M., Harm, R. 1970, ApJ, 160, 341

Shapley, H. 1914, ApJ, 40, 448

Stellingwerf, R. F. 1978, ApJ, 224, 953

Sterken, C. 2005, The Light-Time Effect in Astrophysics: Causes and cures of the O-C diagram, 335, 3

Stetson, P. B. 1987, PASP, 99, 191

Stetson, P. B. 1994, Astronomy with the CFHT Adaptive Optics Bonnette, 72

Stetson, P. B. 2000, PASP, 112, 925

Storm, J., Carney, B. W., & Beck, J. A. 1991, PASP, 103, 1264

Strader, J., Everitt, H. O., & Danford, S. 2002, MNRAS, 335, 621

Templeton, M. R., & Henden, A. A. 2007, AJ, 134, 1999

Turner, D. G., Percy, J. R., Colivas, T., Berdnikov, L. N., & Abdel-Latif, M. A.-S. 2009, American Institute of Physics Conference Series, 1170, 167

Wallerstein, G. 1958, ApJ, 127, 583

Wallerstein, G., & Cox, A. N. 1984, PASP, 96, 677

Yong, D., Lambert, D. L., Paulson, D. B., & Carney, B. W. 2008, ApJ, 673, 854
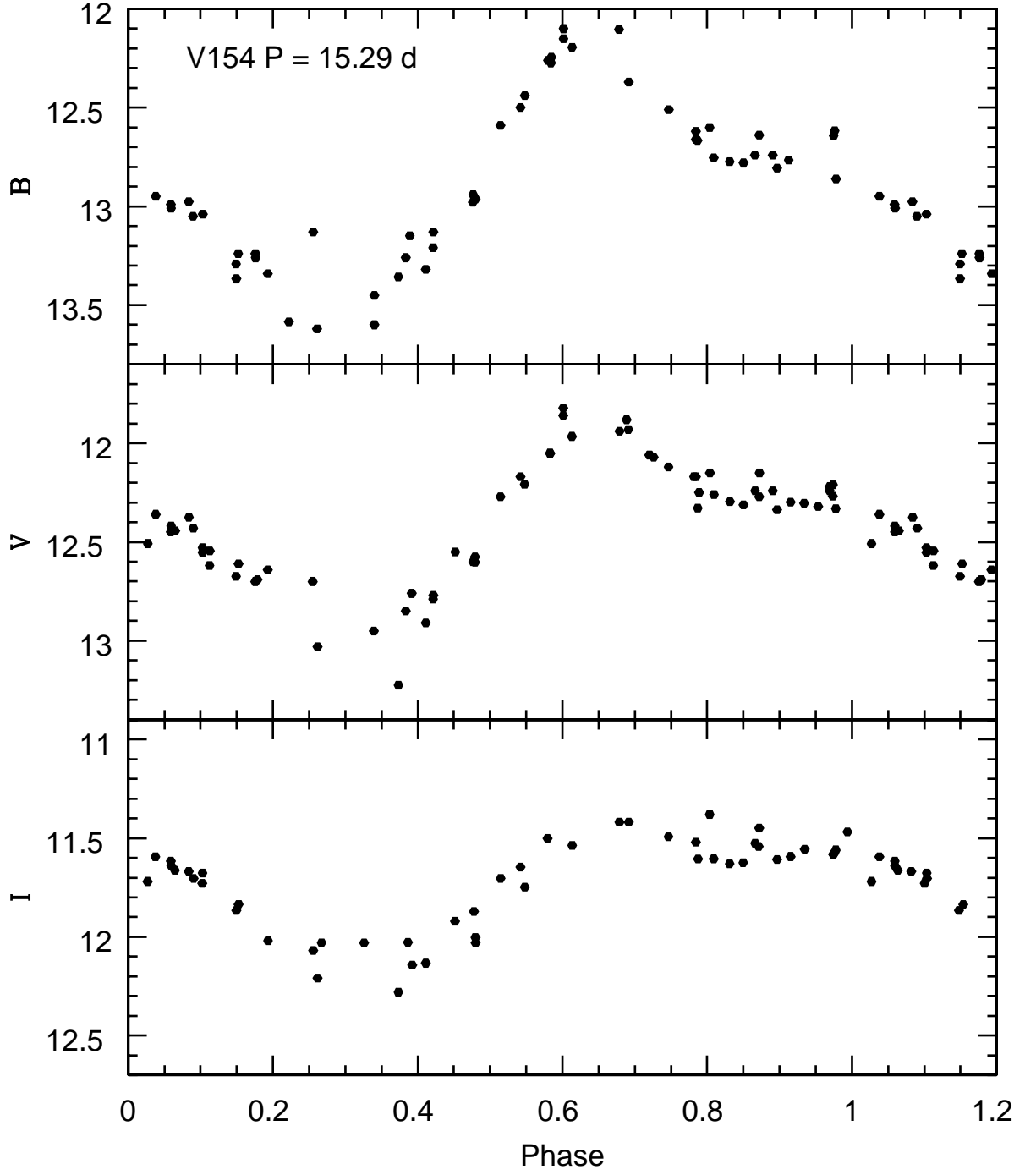
Zinn, R., & West, M. J. 1984, ApJS, 55, 45

Fig. 1.— Light curves for V154 in M3, phased with a period of 15.29 days. The scatter in the light curve is larger than the formal photometric uncertainties, typically 0.02 or 0.03 magnitudes.
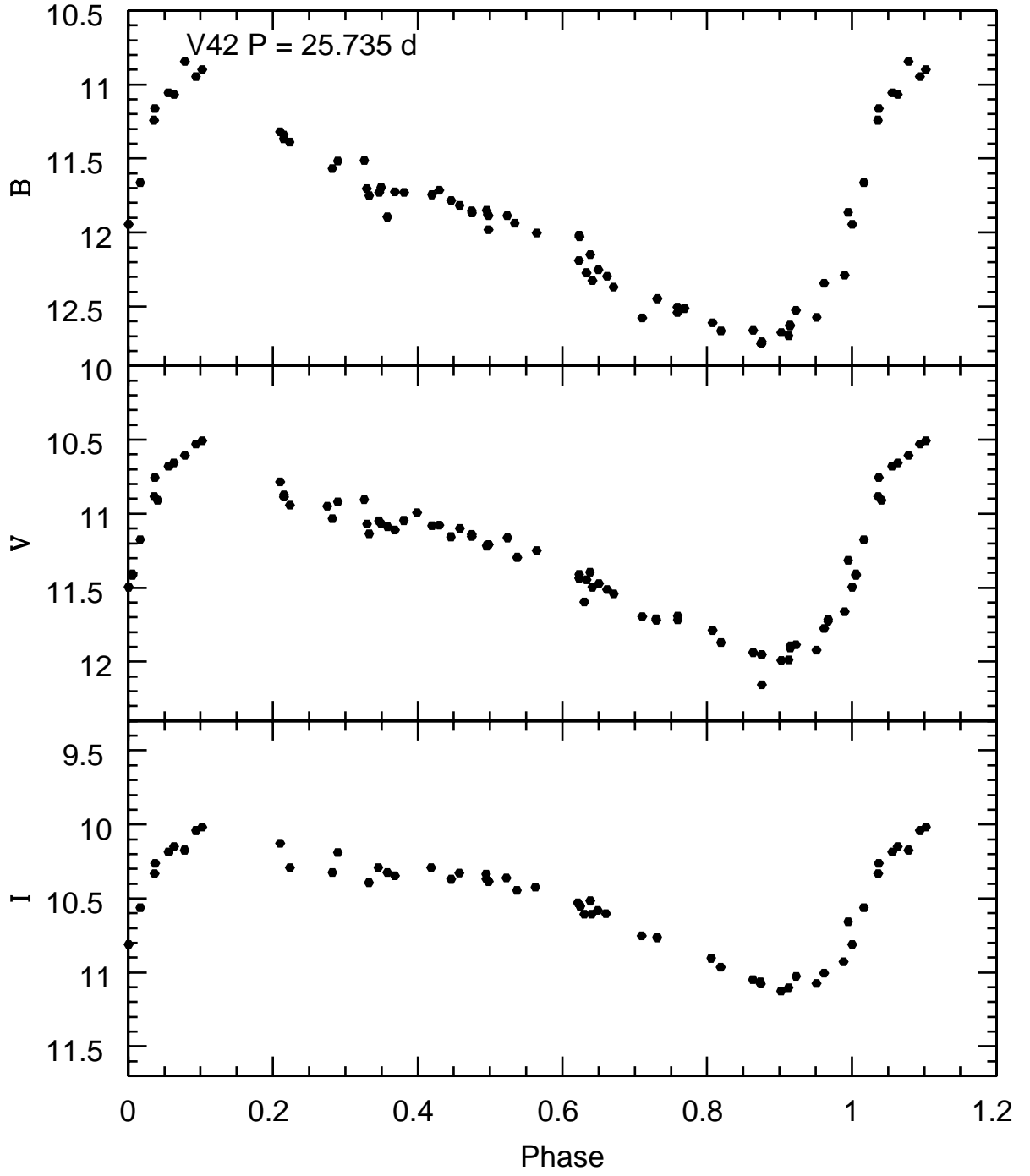
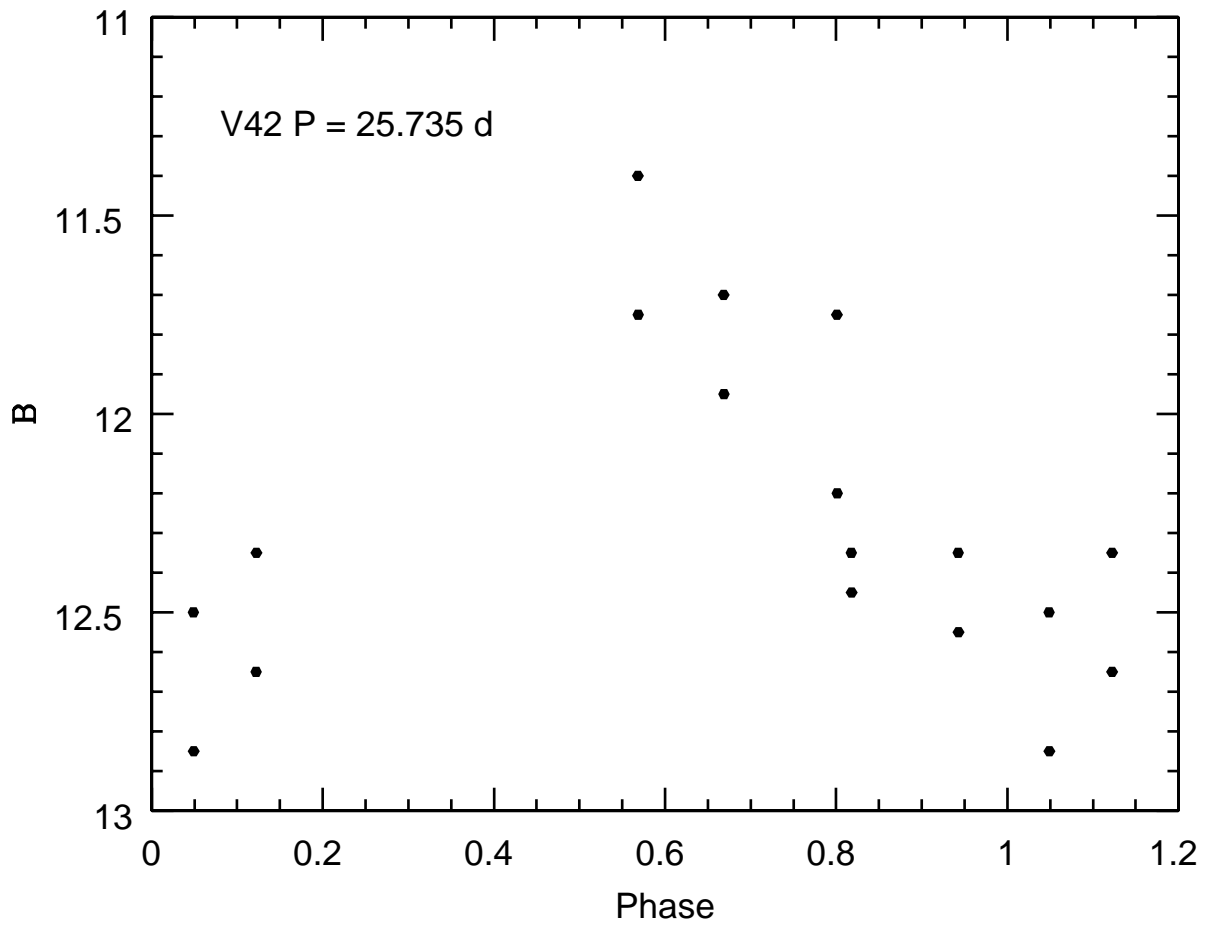Fig. 2.— Light curves for V42 in M5, phased with a period of 25.735 days.

Fig. 3.— *B* band light curve of V42 based upon Yerkes photographic observations, phased with a period of 25.735 days
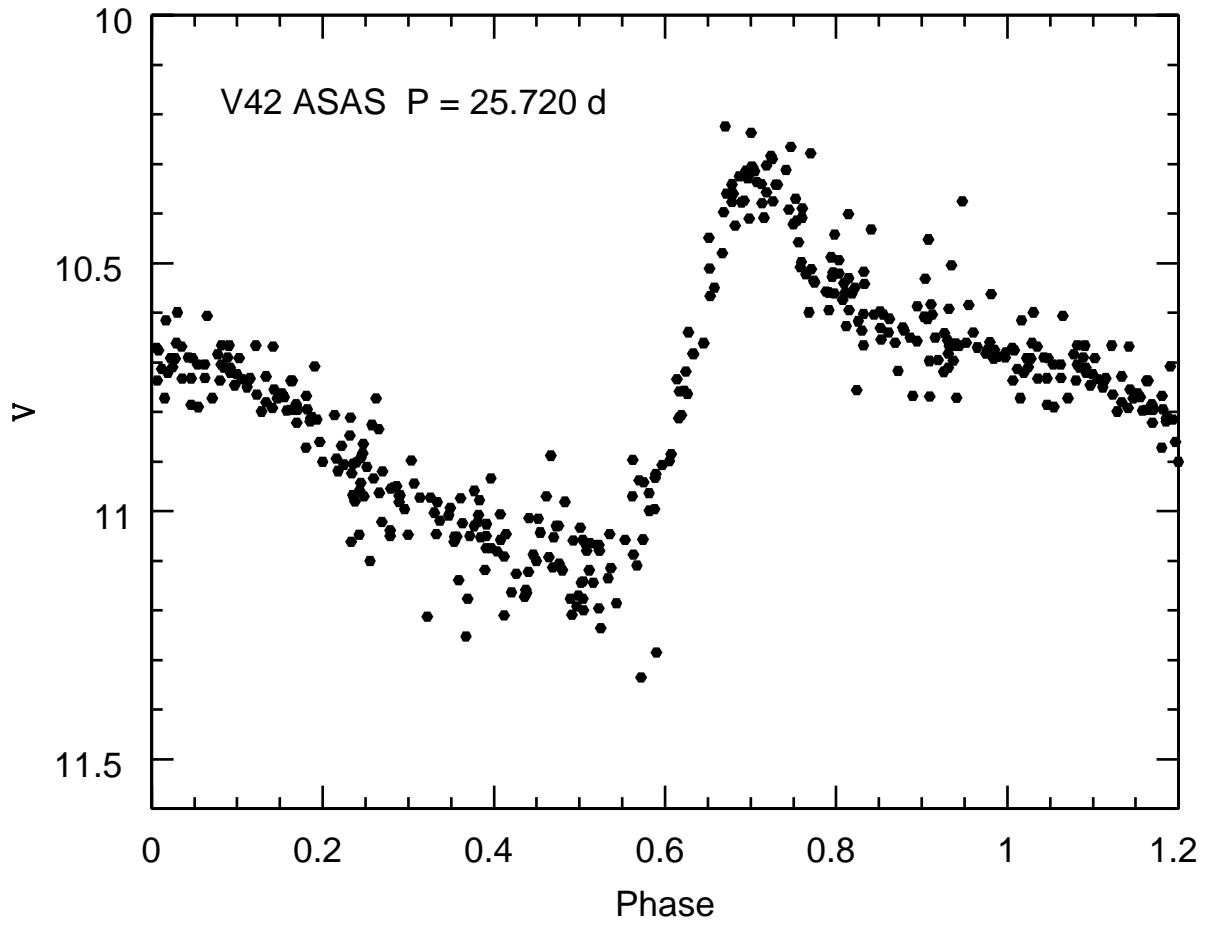
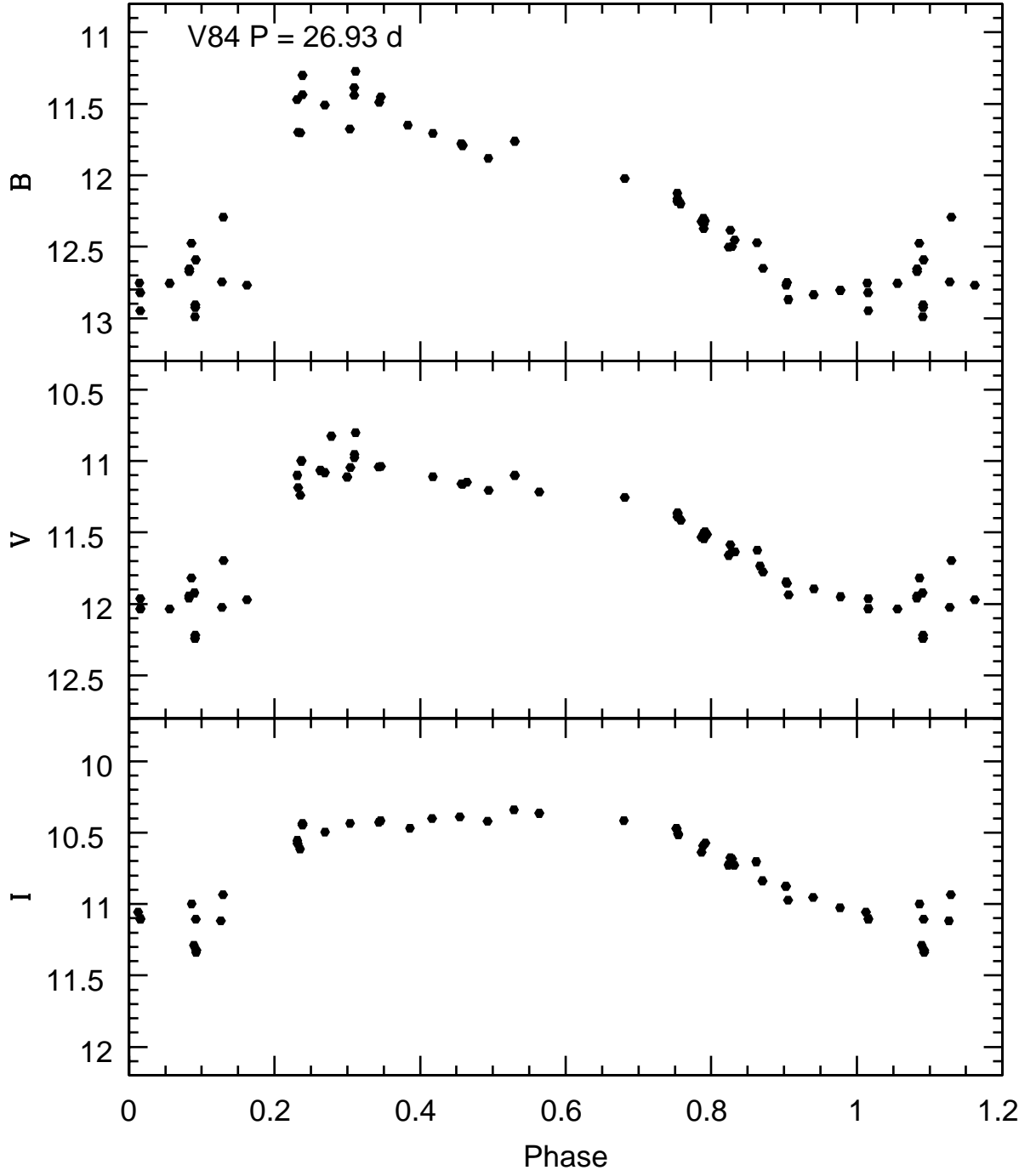Fig. 4.— Aperture photometry of V42 using ASAS data, phased with a period of 25.720 days.

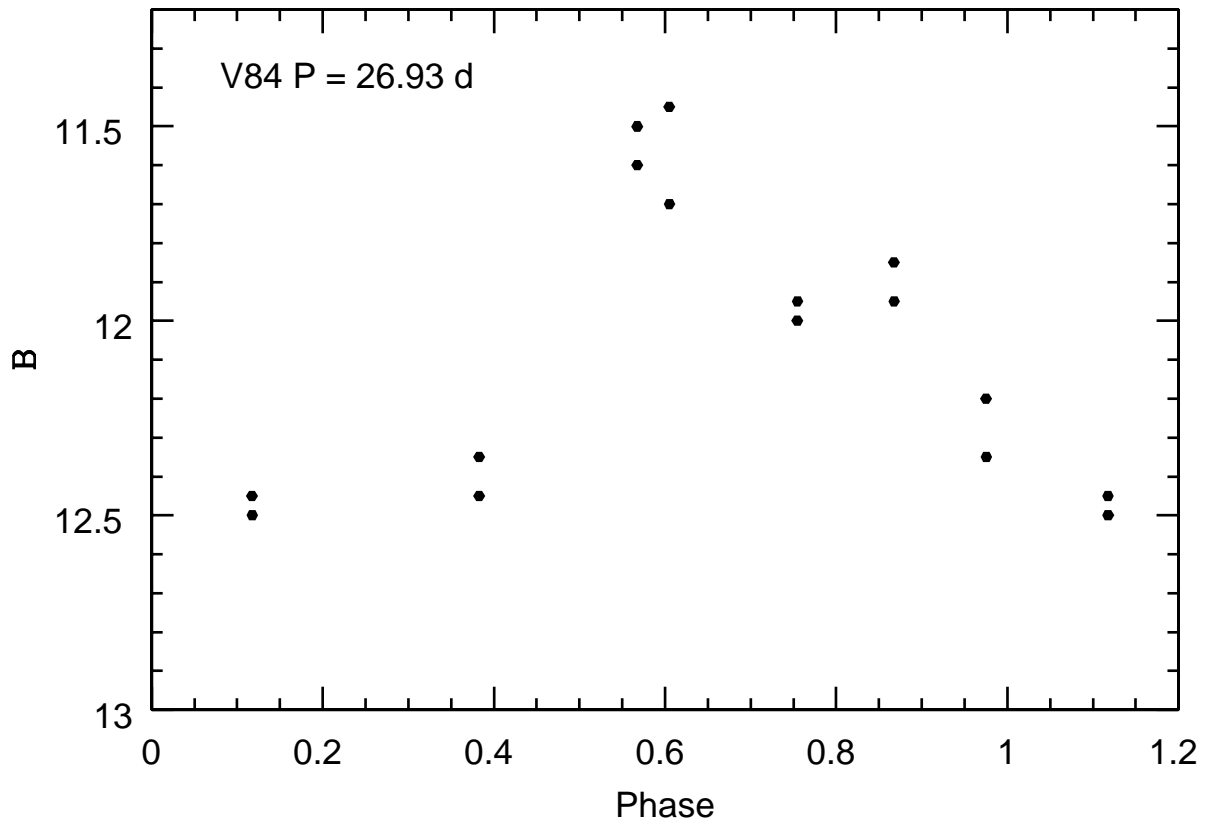Fig. 5.— CCD light curves for V84 in M5, phased with a period of 26.93 days.

Fig. 6.— *B* band light curve of V84 based upon Yerkes photographic observations, phased with a period of 26.93 days.
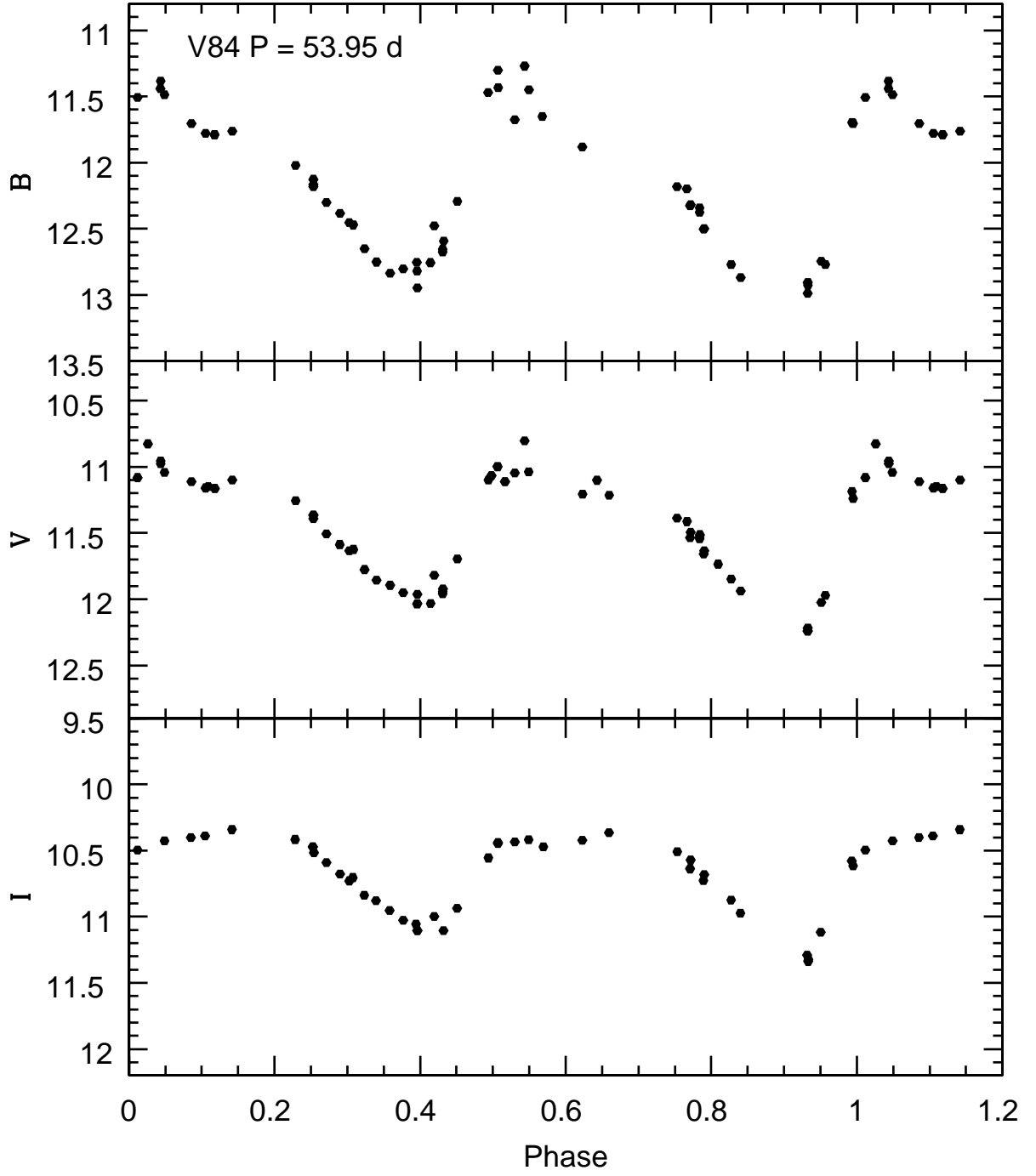
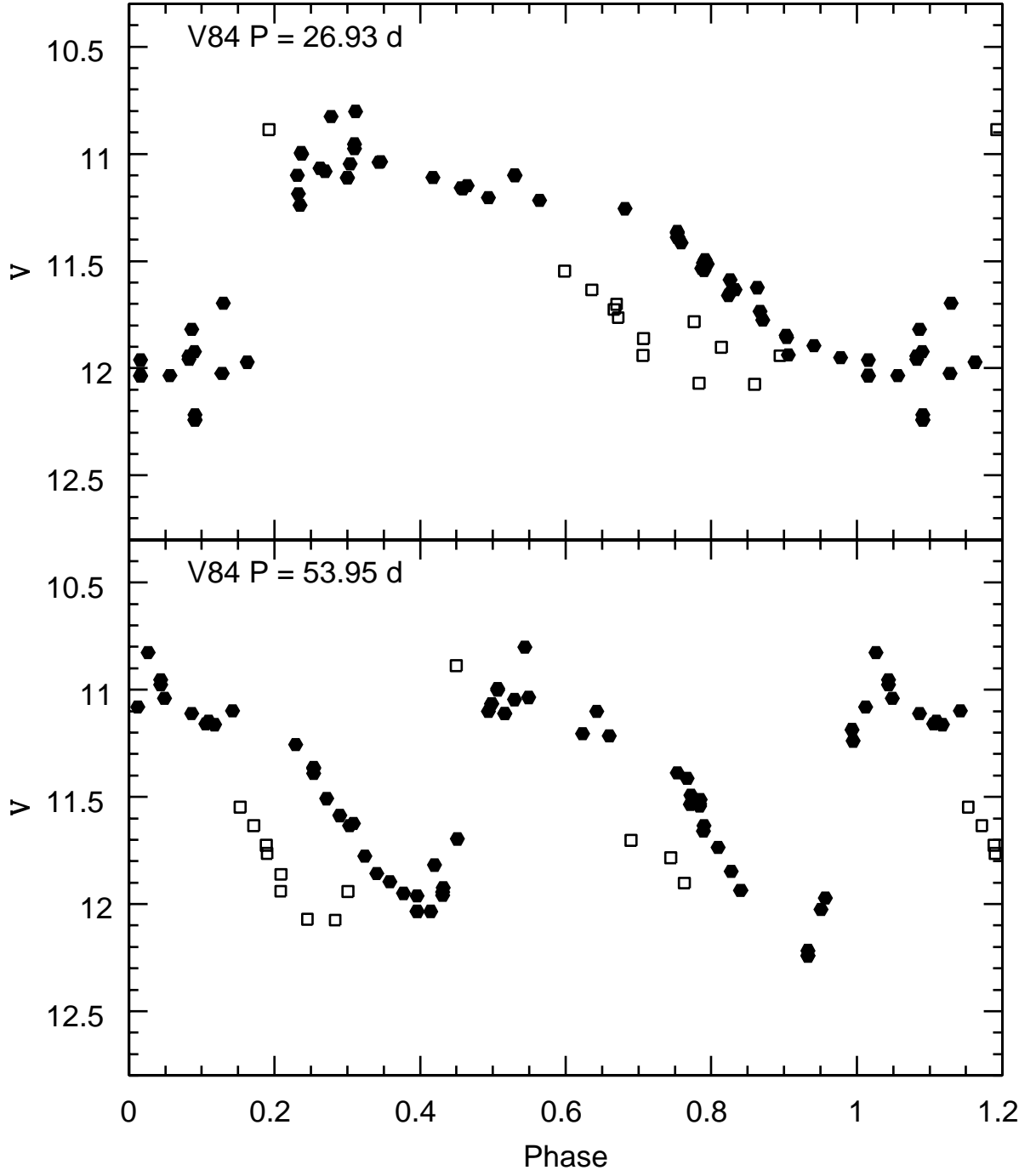Fig. 7.— Light curves for V84 in M5, phased with a period of 53.95 days.

Fig. 8.— Observations from 2006 (open points) and from 2003-2005 (filled points) for the V light curve of V84. The light curves in the other pass bands show similar shifts in phase.
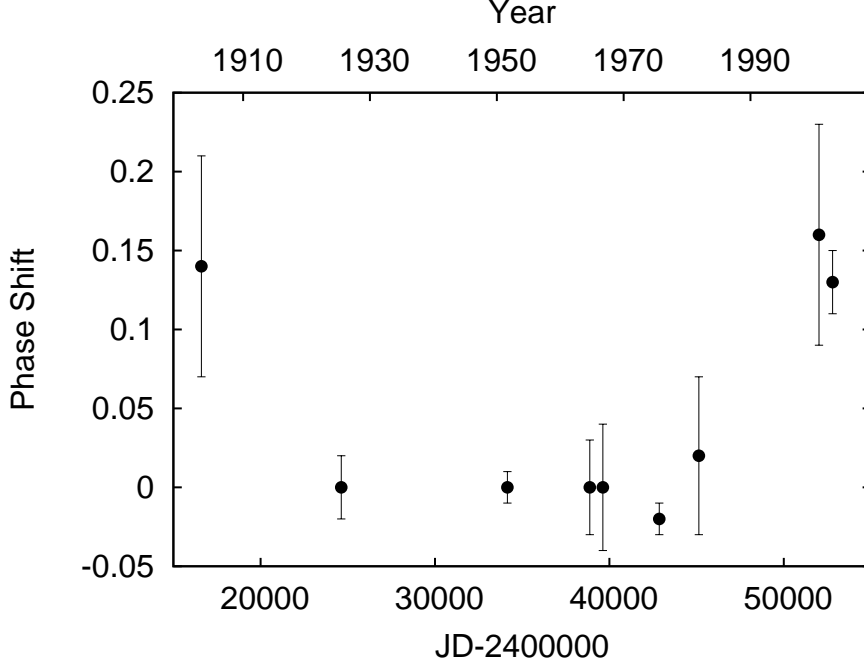
Fig. 9.— Phases of maximum versus Julian Date for V154, calculated assuming a constant period of 15.2854 days.

Table 1. BVI_c Photometry of V154 in M3, V42 in M5, and V84 in M5

Filter	ID	HJD	Mag	Error	Source
B	V154	2452763.5450	13.24	0.03	MSU
B	V154	2452763.5474	13.26	0.03	MSU
B	V154	2452782.5842	13.21	0.02	MSU

Note. — The full version of this table is included in the electronic form of the paper.
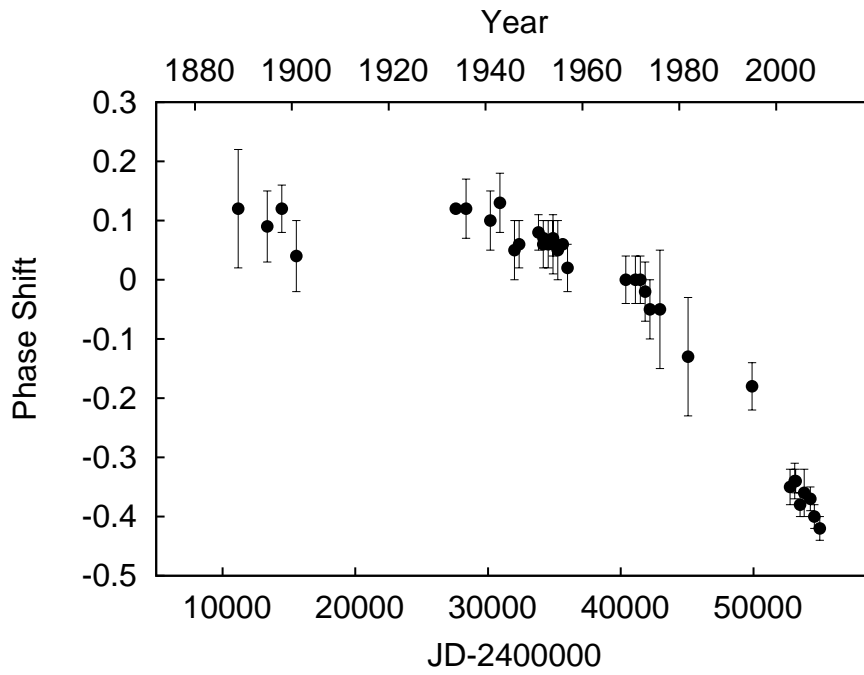
Fig. 10.— Phase shift versus Julian Date for V42, calculated assuming a constant period of 25.738 days. As indicated in Table V of Coutts Clement & Sawyer Hogg (1977), uncertainties are unknown for a couple of the points.
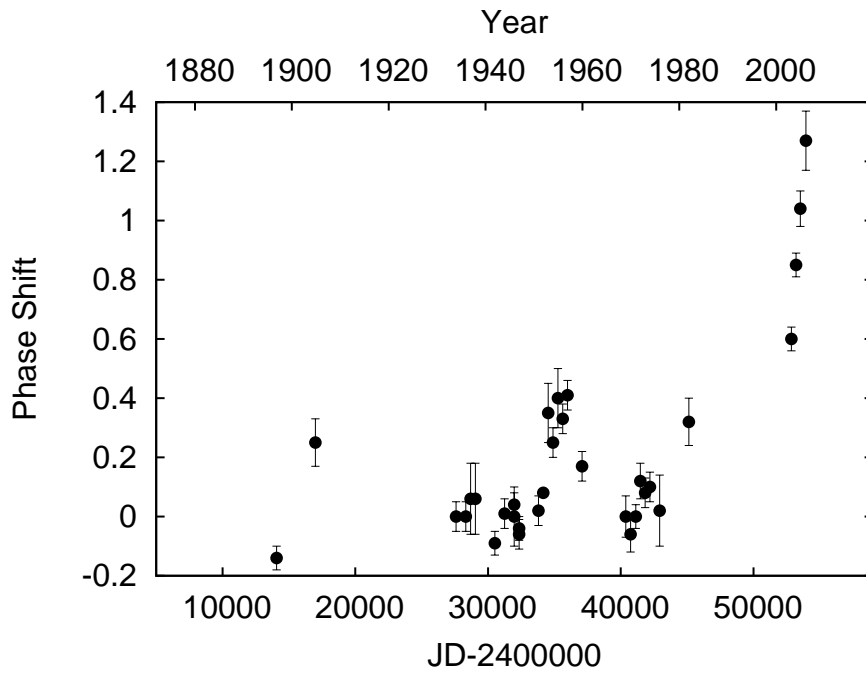
Fig. 11.— Phase shift versus Julian Date for V84, calculated assuming a constant period of 26.42 d. Error bars are not available for one of the points, as indicated in Table V of Coutts Clement & Sawyer Hogg (1977).
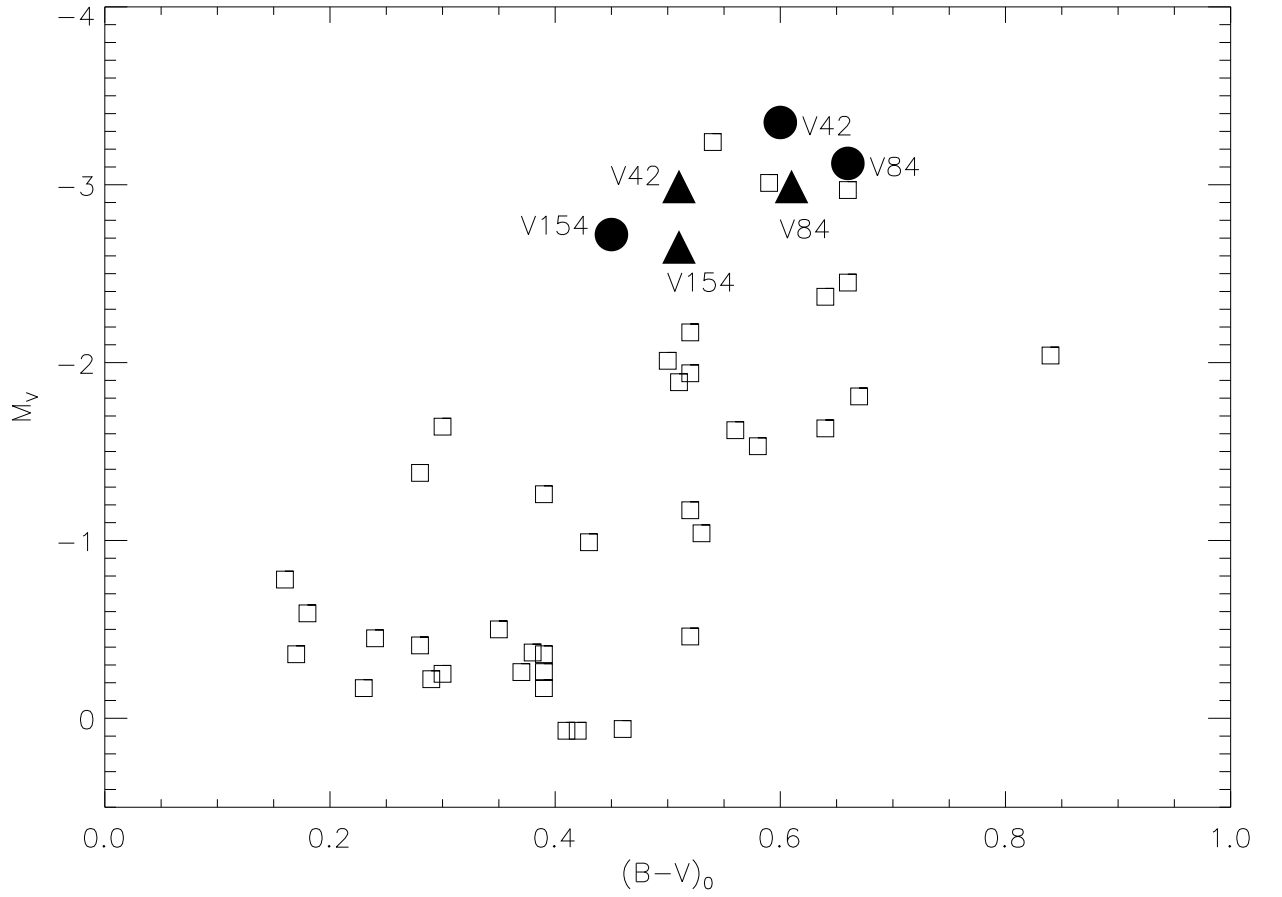
Fig. 12.— Color-magnitude diagram showing type II Cepheids. Open squares and filled triangles represent variables in Nemec et al. (1994). Filled circles represent our results for V154, V42, and V84.

Table 2.   Yerkes Observations

HJD	B(V42)	B(V84)
2445051.9258	12.35	12.0
2445051.9335	12.45	11.95
2445057.8720	12.5	12.2
2445057.8817	12.85	12.35
2445073.8175	11.7	11.5
2445073.8266	11.95	11.6
2445122.7101	11.4	12.35
2445122.7178	11.75	12.45
2445128.6939	11.75	11.45
2445128.7029	12.2	11.7
2445162.6997	12.65	11.85
2445162.7080	12.35	11.95
2445492.6318	12.35	12.45
2445492.6367	12.55	12.5

Table 3.   Phases of Maximum for V154 in M3

JD	Phase	Uncertainty	Source
2416604.6	0.14	0.07	Barnard (1906)
2424627.55	0.00	0.02	Greenstein (1935)
2434150.4	0.00	0.01	Arp (1955)
2438873.53	0.00	0.03	Kholopov (1972)
2439622.55	0.00	0.04	Meinunger (1980)
2442862.71	-0.02	0.01	Hopp (1980)
2451256	0.08	0.08	Benkő et al. (2006)
2452021.5	0.16	0.07	Strader et al. (2002)
2452800.6	0.13	0.02	This paper

Table 4. Phase Shifts for V42 in M5

JD	Phase	Uncertainty	Source
2445073	-0.13	0.1	This paper
2449890	-0.18	0.04	Corwin (priv comm.)
2453170	-0.34	0.02	This paper
2452750	-0.35	0.03	This paper
2453106	-0.34	0.03	This paper
2453509	-0.38	0.02	ASAS
2453821	-0.36	0.04	ASAS
2454284	-0.37	0.02	ASAS
2454583	-0.4	0.02	ASAS
2454991	-0.42	0.02	ASAS

Table 5. Phase Shifts for V84 in M5 from our Observations

JD	Phase	Uncertainty
2445128	0.32	0.08
2452850	0.60	0.04
2453200	0.85	0.04
2453522	1.04	0.06
2453951	1.27	0.10

Table 6. Mean Magnitudes and Colors for the Type II Cepheids

ID	$<V>_{int}$	$<(B-V)>_{mag}$	$<(V-I)>_{mag}$	$<M_V>$
V154	12.33	0.46	0.65	-2.72
V42	11.19	0.63	0.76	-3.35
V84	11.42	0.69	0.80	-3.12